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Research on the Characteristics and Influencing Factors of Spatial Integration of Resource-Based Coal Cities—A Case Study of the Central Urban Area of Huaibei

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Abstract

Background: The integration of mining and urban spaces in coal-resource-based cities holds significant implications for urban transformation and sustainable development. However, existing research lacks an in-depth analysis of its characteristics and driving factors. **Methods:** This study takes the central urban area of Huaibei City as a case, utilizing historical documents, POI data, and spatial analysis methods to explore the evolution patterns and influencing factors of mining–urban spatial integration. Standard deviation ellipse analysis was employed to examine historical spatial changes, while a binary logistic regression model and principal component analysis were constructed based on 300 m × 300 m grid units to assess the roles of 11 factors, including location, transportation, commerce, and natural environment. **Results**: The results indicate that mining–urban spatial integration exhibits characteristics of lag, clustering, transportation dominance, and continuity. Commercial activity density, particularly leisure, dining, and shopping facilities, serves as a core driving factor. Road network density, along with the areas of educational and residential zones, positively promotes integration, whereas water surface areas (such as subsidence zones) significantly inhibit it. Among high-integration areas, Xiangshan District stands as the most economically prosperous city center; Lieshan–Yangzhuang mining area blends traditional and modern elements; and Zhuzhuang–Zhangzhuang mining area reflects the industrial landscape post-transformation. **Conclusions**: The study reveals diverse integration patterns under the synergistic effects of multiple factors, providing a scientific basis for optimizing spatial layouts and coordinating mining–urban development in coal-resource-based cities. Future research should continue to pay attention to the dynamic changes of spatial integration of mining cities, explore more effective integrated development models, and promote the rational and efficient use of urban space and the sustainable development of cities.

Keywords: coal resource-based city; mine–city space; spatial integration characteristics; integration degree evaluation; sustainable development

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1. Introduction

In the urban development history of Huaibei, the evolution of "mines within cities" has played a crucial role. Throughout this process, "mines within cities" have accompanied the city's development, undergoing various stages such as mine establishment, city formation, prosperity, decline, and transformation, profoundly influencing the spatial development of Huaibei's urban areas [1–3]. With the separation of social functions from state-owned enterprises, the integration of "mines within cities" and urban spaces has become an unavoidable issue in the city's development [4,5]. As a key component of the spatial structure of coal resource-based cities, the spatial evolution of "mines within cities" not only reflects the rise and fall of mining areas but also mirrors the city's development and transformation to some extent. Therefore, focusing on the integrated development of mine–city spaces and extracting spatial integration characteristics and influencing factors is of great significance for the in-depth integration development and urban transformation of coal resource-based cities.

Currently, research on the spatial integration development of coal resource-based cities mainly revolves around spatial evolution patterns, mine–city interactive development, and driving mechanisms. Among them, Yuan Zuhuai, Cao et al. established a systematic model of city–mine coordinated development to explore urban land expansion characteristics and utilization efficiency within the context of resource-based cities. This provides critical references for understanding the transition of development models and their driving mechanisms in coal resource-based cities across distinct development periods [6–9]. Jiao Huafu and others analyzed the coupling mechanism between industrial structure evolution and urban spatial morphology evolution in coal resource-based cities, suggesting that the spatial morphological evolution in these cities is a result of the self-repair of production factors through spatial effects during industrial structure evolution [10,11]. Wu Xiao and others conducted a spatial description and quantitative investigation of the differentiation characteristics of social space and population migration in resource-based cities, revealing the evolutionary patterns of social space and urban shrinkage [12–14]. Zhang Peng, Zhang Y, and others, based on the FLUS-UGB model and the "RIC" framework of green infrastructure (GI), focused on mine–city interactive development, providing reference for coordinating the utilization of regional urban development space and mining resources [15–17]. Zhang Zongtang, Kapanski A, and others focused on addressing subsidence, collapse, and advancements in underground space technology and road infrastructure construction techniques caused by underground mine excavation, aiming to mitigate the negative impacts of coal mining on urban spaces [18–22]. Xue Wei proposed achieving coordinated development between mining areas and urban areas in aspects such as ecological environment governance, industrial economic development, and social issue resolution [23–25]. Xia Min analyzed the change characteristics of industrial and mining land using land use dynamics and land use transfer matrices, constructed a simulation model for industrial and mining land changes, and conducted a quantitative study on its driving mechanisms based on multi-agent systems [26–28]. Existing studies mostly focus on macroscopic evolutionary patterns while lacking a quantitative analysis of multi-factor synergistic effects. Few scholars have used POI data to explore the spatial integration characteristics of mining cities. This study innovatively integrates grid-based analysis of multi-source data with historical evolution and quantitatively analyzes the synergistic effects of influencing factors, effectively expanding the research framework for coal resource-based cities [29,30].

For coal resource-based cities, urban space is influenced by both coal mining and urbanization, exhibiting distinct spatial isolation characteristics. Therefore, exploring the measurement system of spatial integration in coal resource-based cities, revealing the

process and key influencing factors of mine–city spatial integration under the impacts of coal mining and urbanization, and analyzing the reasonable development model of mine–city spatial integration, this study proposes an evaluation framework for mine–city spatial integration. Under the context of "dual carbon goals" and "urban renewal," it provides differentiated practical pathways for sustainable urban space development.

2. Materials and Methods

2.1. Study Area

Huaibei City is located in the heart of East China, with geographical coordinates between 33°16′ N and 34°14′ N latitude and 116°23′ E and 117°02′ E longitude. It lies at the confluence of Jiangsu, Henan, and Anhui provinces, bordered to the north by Xiao County, to the east by Suzhou, to the west by Guoyang and Yongcheng in Henan, and to the south by Huainan. The city stretches 108 km from north to south and 60 km from east to west, covering a total area of 2741 square kilometers. Administratively, it comprises four districts: Xiangshan District, Duji District, Liehu District, and Suixi County, with a permanent population of approximately 1.95 million [31]. The scope of this study focuses on the central urban area of Huaibei City (see Figure 1).

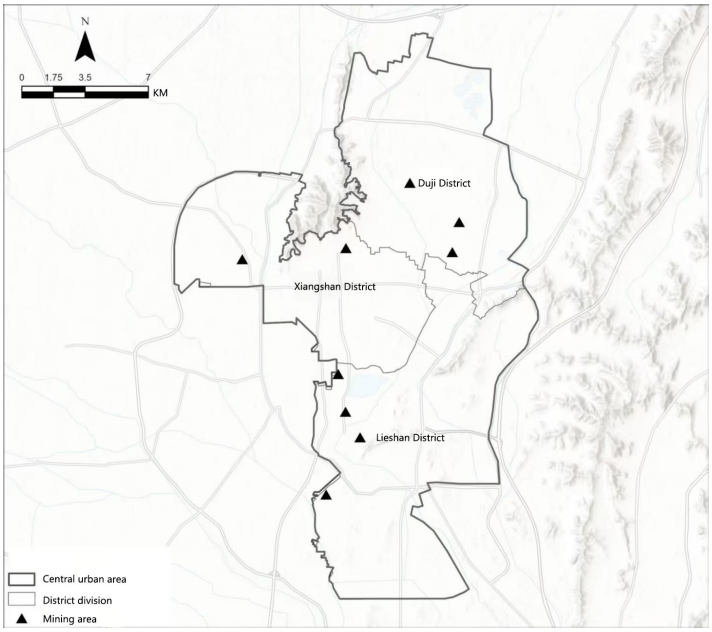


Figure 1. The extent of the central urban area of Huaibei City.

2.2. Data Source

Based on a systematic review and compilation of the Huaibei City Annals, Huaibei Mining Bureau Annals, and individual mining area chronicles, spatial data on each mine and its associated facilities were collected and categorized according to different historical phases. This information was then integrated with the 1972 base map of Huaibei's urban area and current urban imagery to delineate the initial locations of relevant factories and mines. This process enabled the identification of the spatial influence boundaries within the research area during the mine-city spatial integration process.

For analyzing influencing factors of mine–city spatial integration, spatial information on "mines within cities" was primarily sourced from July 2024 Tencent Map POI data with geographic coordinates, covering living services, residential areas, and commercial offices.

2.3. Research Method

To deeply reveal the spatial integration characteristics of coal resource-based cities, this study employs traditional spatial analysis methods to review and organize the spatial changes in mining cities since their establishment, focusing on exploring the characteristics of spatial integration and the driving factors behind them (see Figure 2).

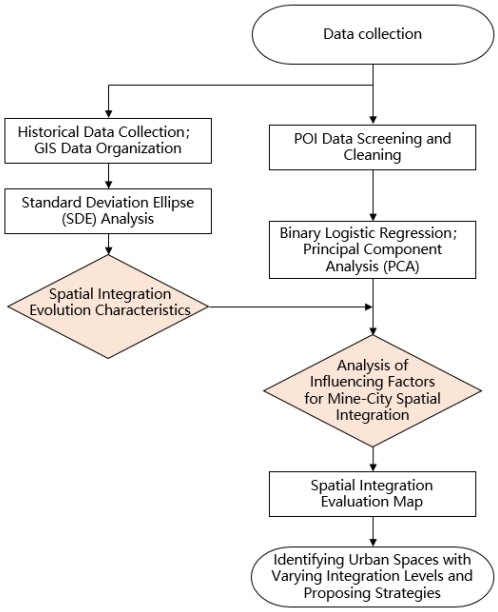


Figure 2. Research framework.

2.3.1. Study on the Evolution of Mine–City Spatial Integration

The Standard Deviation Ellipse (SDE) is a method for quantifying the directional trend of a set of points or regions. It calculates standard distances along the x, y, and z axes to define the axes of an ellipse (or ellipsoid) encompassing the distribution of all features. This ellipse, termed the Standard Deviation Ellipse, analyzes spatial directional characteristics and has become a standard statistical tool in GIS spatial analysis modules.

The study utilizes Standard Deviation Ellipse (SDE) to visually reflect spatial structural characteristics such as the distribution range, mean center, orientation, and dispersion degree of historical mine–city spaces [32–34]. By comparing the spatial patterns of mine–cities across different historical stages, the study aims to uncover the spatial development directions and integration features of each phase [35].

2.3.2. Analysis of Influencing Factors of Mine-City Spatial Integration

The POI data were cleaned by removing duplicate and inaccurate coordinates, historical maps were georeferenced using ArcGIS 10.8, and all grid-based calculations were automated via Python 3.7.8scripts.

Based on the correlation between "mines within cities" and urban development during historical stages, four categories of factors—location, spatial, transportation, and commercial—comprising 11 specific factors, are selected to measure the current state of mine-city integration in Huaibei's central urban area [36–38]. Based on the 15 min walking distance range for populations, this study defines the average distance of mine–city spatial influence and adopts a 300 m × 300 m grid as the analysis unit. The 300 m × 300 m grid ensures sufficient Point of Interest (POI) samples (e.g., commercial facilities, residential areas) within each unit while avoiding masking local variations due to excessive grid size, meeting the requirements of urban spatial heterogeneity analysis. The study area contains a total of 3813 analysis samples [39,40].

In examining these influencing factors, a binary logistic regression model is employed to test the correlation of each factor. Binary Logistic regression analysis is appropriate when the dependent variable is binary, quantifying the impact of independent variables on the probability of a binary outcome. Compared to other models, it is particularly suitable for analyzing grid-based spatial data and is widely applied in fields such as commercial geography and economic analysis [41–43]. In this context, when a grid within the study area is influenced by mine–city spatial integration, the dependent variable (y) is assigned a value of 1; otherwise, it is 0. The 11 factors identified earlier serve as independent variables in the analysis. The regression equation is as follows:

$$\ln\frac{p}{1-p} = b_0 + b_1x_1 + \ldots\ldots b_kx_k \quad (1)$$

In the regression equation, p represents the probability of event y occurring, x_1, x_2, …, x_k are the independent variables, and b_0, b_1, …, b_k are the regression coefficients, indicating the strength of association between each independent variable and p.

Commercial density is calculated using the kernel density estimation method, with the formula:

$$\rho(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} K\left(\frac{d_i}{h}\right) \quad (2)$$

where $\rho(x,y)$ denotes the commercial density at location (x,y), n represents the total number of commercial facilities, h is the bandwidth parameter (set to 300 m), K stands for the kernel function, and d_i indicates the distance from the i-th commercial facility to the calculation point.

Spatial integration analysis refers to determining the degree of integration between two spatial entities based on attributes such as social, economic, and ecological characteristics of urban spaces. Principal Component Analysis (PCA) is applied to reduce dimensionality among correlated influencing factors, categorizing multivariate data into composite indices with assigned weights [44–46]. This approach facilitates scoring the degree of mine–city spatial integration development in Huaibei's central urban area and, based on these scores, identifying the developmental directions of mine–city spaces with varying levels of integration, as summarized in Table 1.

Table 1. Evaluation criteria for spatial integration of resource-based coal cities.

Influence Type	Influence Factor	Variable Nature	Variable Definition
Location Factors	Educational Facilities	Independent Variable	Area of educational zones intersecting or contained within the unit
	Residential Land	Independent Variable	Area of residential zones intersecting or contained within the unit
	Green Spaces and Parks	Independent Variable	Area of green spaces and parks intersecting or contained within the unit

Table 1. *Cont.*

Influence Type	Influence Factor	Variable Nature	Variable Definition
Spatial Factors	Collapsed Area Water System Proportion	Independent Variable	Area of pond water bodies intersecting or contained within the unit
	Mining Area Space	Independent Variable	Whether the unit intersects or contains mining area space (including mines, factories, workers' villages, and living facilities)
Transportation Factors	Road Network Density	Independent Variable	Length of roads intersecting or contained within the unit
Commercial Factors	Dining Establishments	Independent Variable	Number of dining industry establishments intersecting or contained within the unit
	Shopping Venues	Independent Variable	Number of shopping industry establishments intersecting or contained within the unit
	Leisure and Entertainment Venues	Independent Variable	Number of leisure and entertainment industry establishments intersecting or contained within the unit
	Hotel Services	Independent Variable	Number of hotel service industry establishments intersecting or contained within the unit

3. Results

3.1. Analysis of the Historical Evolution of the Mine–City Space in Huaibei City

The historical records of Huaibei City's central urban area reveal that the degree of spatial integration between "mines within cities" and urban development is not a simple linear relationship with the prosperity of mining areas. By observing the urban development process, one can examine the rise and fall of "mines within cities" and the migration patterns of workers to extract the characteristics of mine-city spatial integration.

3.1.1. Transformation Characteristics of Mine–City Space

Based on historical urban planning documents from the Huaibei Urban Planning Exhibition Hall—including the 1962 Suixi City Master Plan (Short-term Layout Map), Huaibei City Master Plan Land Use Current State Map (1979–2000), Northern Huaibei District Master Plan (1991–2010), and Northern Huaibei District Urban Current State Map (1995)—along with other relevant materials, the spatial evolution of the Huaibei mine–city can be divided into five historical stages: 1960–1978, 1979–1990, 1991–2005, 2006–2015, and 2016-present. The evolution of the mine–city space in different development periods in Huaibei City has been analyzed by compiling data on the formation and development of "mines within the city" in the central urban areas of each historical stage, with an in-depth analysis of the spatial integration patterns and characteristics at each time point, as shown in Figure 3.

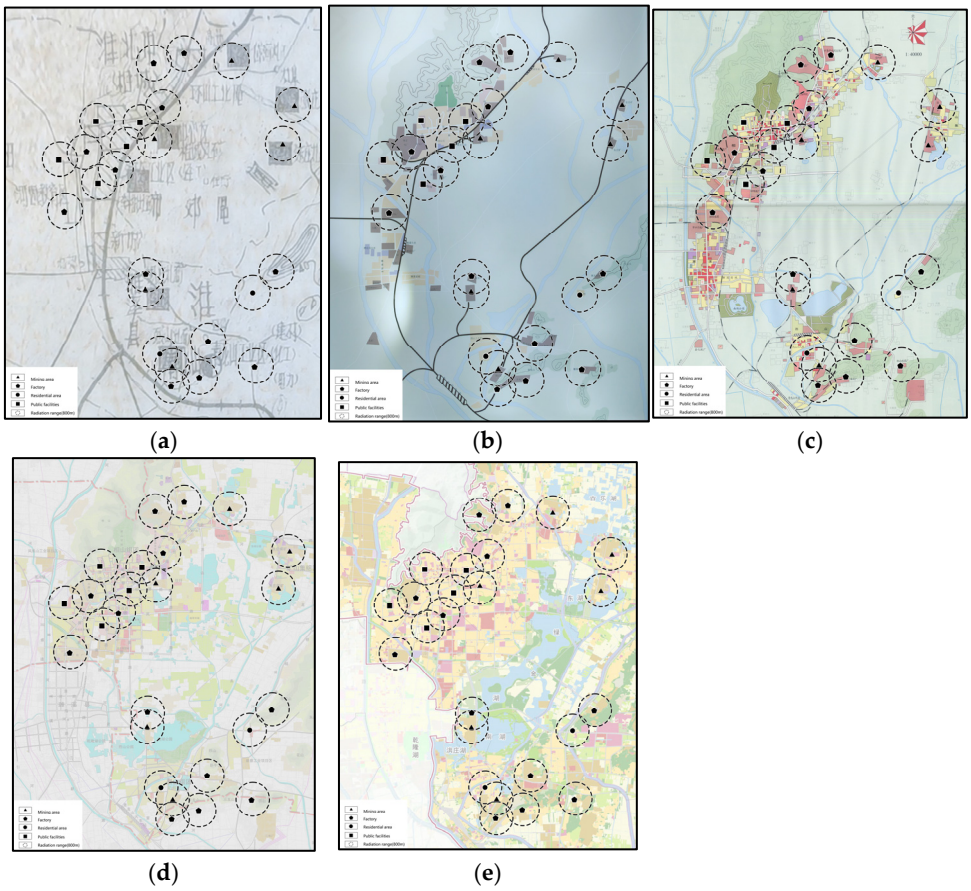


Figure 3. Evolutionary process of spatial integration in Huaibei's mining city over the years: (**a**) 1960–1978; (**b**) 1979–1990; (**c**) 1991–2005; (**d**) 2006–2005; (**e**) 2016–Present.

By mapping the locations of mining areas and related facilities, the following can be observed. (1) 1960–1978, Germination Period: During the planned economy period, the mining areas developed in scattered points, each independently. The "mines within the city" were the main spatial carriers of the central urban area of Huaibei, mostly distributed around the coal industry and areas related to workers' livelihoods. (2) 1979–1990, Transition Period: With an increase in the influx of population and the emergence of the market economy, Huaibei entered a dual-track system of planned and market economies. The residential areas around the mining areas expanded, and the mine–city space began to connect significantly, with the city gradually merging into a unified space. (3) 1991–2005, Reshaping Period: During the period of economic reforms, the rise of unemployment caused by the closure of state-owned enterprises led to a gradual diversification of the economic structure in Huaibei, with urban space beginning to significantly exceed the "mines within the city" space, showing an encircling trend. (4) 2006–2015, Growth Period: During the period of full marketization, urban space grew on a large scale, and the mine–city space integrated into a unified whole. (5) 2016-present, Transformation Period: In 2021, the national land and space planning was revised, and urban space is no longer simply based on the mine–city relationship. Instead, it redefines urban development units based on the mine and city, in line with the spatial needs of industrial transformation. The mine–city space has started to develop in a composite and three-dimensional way.

In terms of the overall change trend, the degree of spatial integration of the Huaibei mine–city has significantly deepened over the past thirty years. Although the average displacement is small, the directional trend has become increasingly apparent. Some peripheral "mines within the city" areas have become new growth poles for urban space

development. In particular, the integration of mine–city space on the east and south sides has been continuously strengthened. This change trend is highly consistent with the migration and expansion process of the center of Huaibei City, as shown in Figure 4.

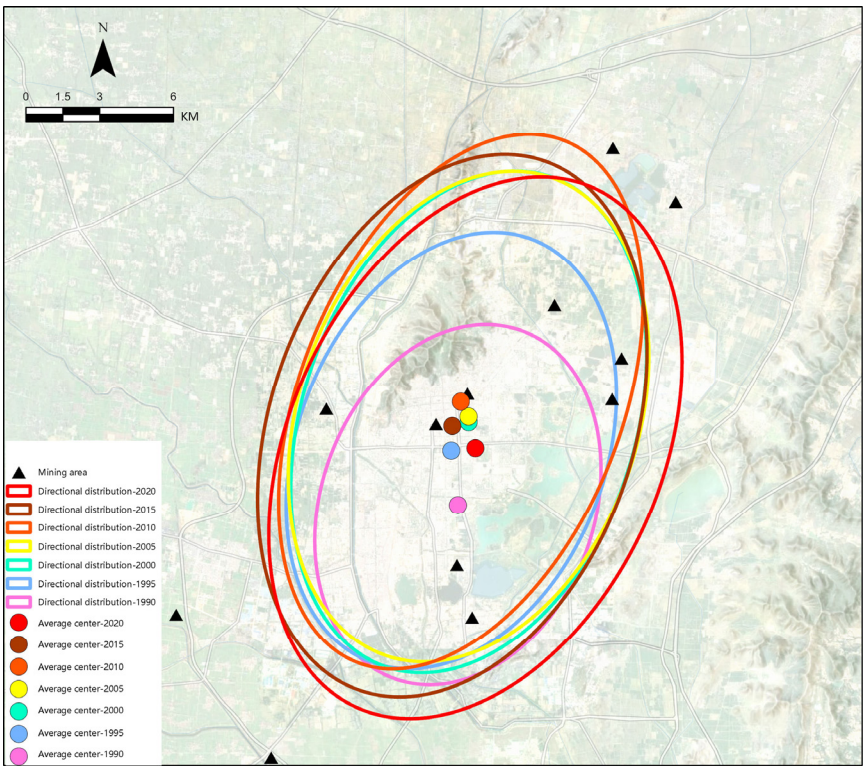


Figure 4. Process of spatial centroid shift in the central urban area of Huaibei City.

3.1.2. Summary of Spatial Integration Characteristics and Patterns

In the various stages of mine–city space development, the emergence of "mines within the city" and the process of integration with the urban areas exhibit distinct characteristics of coal resource-based cities. The integration of mine–city space follows a general pattern of "large integration, small independence, and gradual decline."

The integration of the mine–city space in Huaibei City has the following characteristics. (1) Delayed Integration: Affected by the distribution of mineral resources, the emergence of mining areas is often not a linear process. This leads to the city being fragmented by the development of mining areas during the early stages, with urban space failing to follow the development of mining areas in a timely manner. (2) Spatial Clustering: The process of spatial integration in Huaibei City shows a distinct regional clustering characteristic. Due to the relatively large distance between each mining area, urban public service facilities cannot fully cover the mining areas. As a result, each area needs to independently provide complete social functions to serve the workers' needs, with clear spatial clustering. (3) Traffic Dominance: The changes in the integration of mine–city space are highly related to the degree of traffic connectivity in Huaibei City and the transportation demands for coal resources. It is significantly influenced by the railway and road networks, showing characteristics of development along transportation lines. (4) Spatial Continuity: After the closure of the "mines within the city," the original mining area can continue to exist through the preserved worker villages and public service facilities, which, to some extent, promote the development of surrounding urban areas. With the integration of mine–city spaces, the integration among citizens gradually deepens. As the management model of the mining area transitions from an enterprise management model to a government-managed model, the identity recognition of the mining workers also gradually changes.

3.2. Mine–City Space Integration Measurement in Huaibei City

3.2.1. Integration of Mine–City Space in Huaibei City

Referring to the 1979 mining area map of Huaibei City, there are a total of 41 related mine–city spatial sites in the central urban area, mainly located in regions such as Xiangcheng District and Liehu Mountain District. As shown in Figure 5, the mining areas are now all situated within the central urban area, with a significant support of the mining space for the urban space.

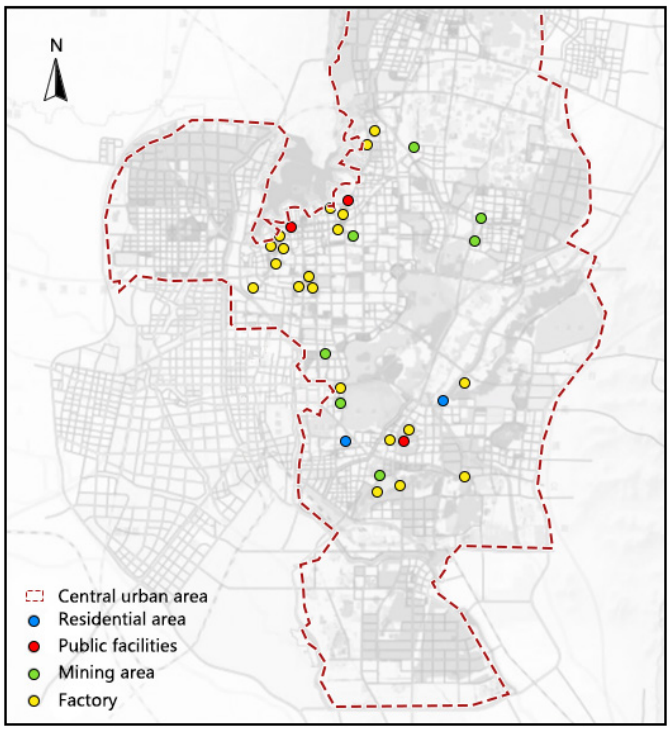


Figure 5. Spatial distribution map of industrial and mining facilities in Huaibei City.

By comparing the distribution of mining areas across different stages, it can be observed that the current mining areas in the central urban area overlap significantly with the historical distribution of mining areas in terms of geographical location. Compared to the previous century, the current distribution range has expanded and is now extending along transportation lines.

3.2.2. Analysis of Influencing Factors

Based on the current state of the mine–city space in Huaibei City, spatial integration measurement is conducted. First, an independent sample *t*-test is performed for each independent variable and dependent variable to measure the magnitude of the group differences. The larger the *t*-value, the more significant the difference between groups. The *p*-value is used to assess the significance of the difference, with a *p*-value < 0.05 indicating a significant difference, and a *p*-value < 0.01 indicating a highly significant difference. As shown in Figure 6 and Table 2, the number of hotels has a *t*-value of 7.304 and a very low *p*-value, indicating a significant difference in the number of hotels between the "existing group" and the "non-existing group." The increase in the number of hotels may attract more tourists, contributing to the integration of the mine–city space. The leisure and entertainment facilities have a *t*-value of 14.272, the highest significance [47]. This indicates a close relationship between the presence of leisure and entertainment facilities and the integration of mine–city space, making it a key influencing factor. The number of dining facilities has a *t*-value of 13.339 with an extremely low *p*-value, showing a significant

correlation between the number of dining facilities and the integration of mine–city space, which may provide dining convenience for residents. The number of shopping facilities has a *t*-value of 10.062 and a very low *p*-value, indicating that the presence of shopping facilities increases the area's attractiveness and promotes the integration of mine–city space. The area of educational zones has a *t*-value of 5.126, which is significant, indicating that the area of educational zones has some impact on the integration of mine–city space, but it is not as significant as commercial facilities. The area of parks and green spaces has a *t*-value of 1.873 and a *p*-value close to 0.06, which does not reach a significant level, indicating that parks and green spaces have a minor impact on the integration of mine–city space, but have potential ecological benefits. The area of residential zones has a *t*-value of 10.854 and a very low *p*-value, suggesting that an increase in the area of residential zones may provide a potential population base for the integration of mine–city space. The area of water surfaces has a *t*-value of −11.246 and a very low *p*-value. The negative value indicates that the area of water surfaces has a negative impact on the integration of mine-city space, likely because water bodies (such as coal mining subsidence areas) restrict the smooth flow of urban movement. The mining area has a *t*-value of 9.762 and a low *p*-value, indicating a significant impact of mining areas on urban space. The road network density has a *t*-value of 15.963 and an extremely low *p*-value, suggesting that areas with higher road density are more conducive to the integration of mine–city space, highlighting the importance of transportation convenience. The spatial fragmentation degree has a *t*-value of 1.001 and a non-significant *p*-value, indicating that the spatial fragmentation caused by coal transport railways has a minimal effect on the integration of mine–city space.

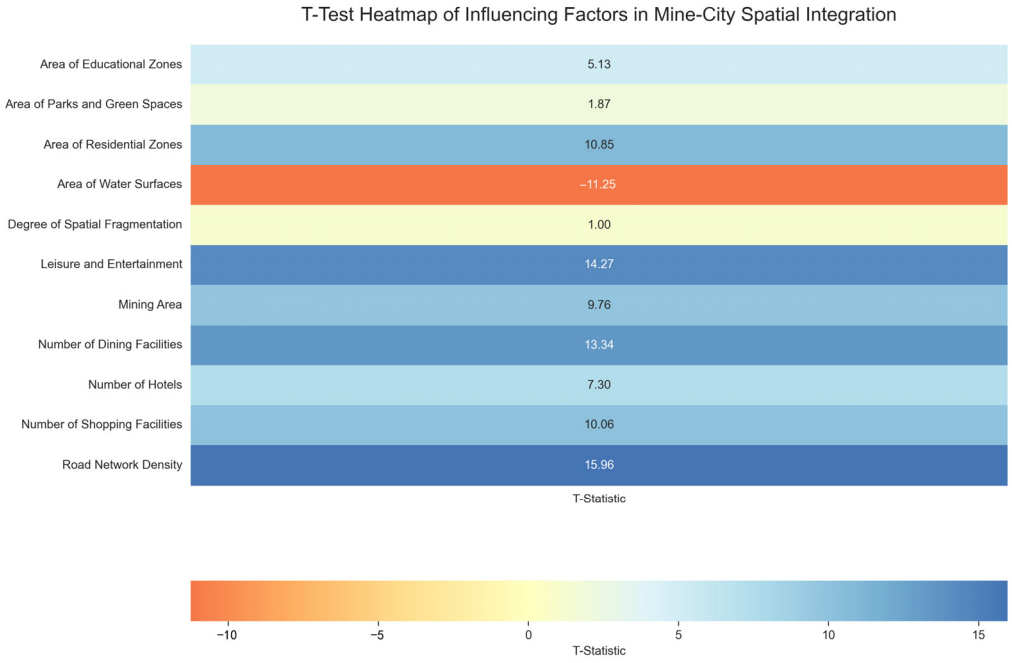


Figure 6. Results of independent samples *t*-test.

At the same time, a binary logistic regression model was constructed using the indicators to control for confounding factors and perform regression analysis on the data, as shown in Table 3.

The regression coefficient indicates the direction and strength of the independent variable's effect on the dependent variable [48]. A positive value represents a positive effect, while a negative value represents a negative effect. The odds ratio represents the rate at which the independent variable affects the dependent variable [49]. A value greater than 1 indicates a positive effect, while a value less than 1 indicates a negative effect.

Table 2. Results of independent samples *p*-value.

Independent Variable	*p*-Value
Number of Hotels	2.150714×10^{-12}
Leisure and Entertainment	3.090945×10^{-36}
Number of Dining Facilities	1.072113×10^{-32}
Number of Shopping Facilities	6.298613×10^{-21}
Area of Educational Zones	4.897981×10^{-7}
Area of Parks and Green Spaces	6.195168×10^{-2}
Area of Residential Zones	8.681289×10^{-24}
Area of Water Surfaces	3.098874×10^{-27}
Mining Area	3.917728×10^{-20}
Road Network Density	2.769623×10^{-44}
Degree of Spatial Fragmentation	3.174559×10^{-1}

Table 3. Results of logistic regression analysis.

Variable	Coefficient	Odds Ratio
Number of Hotels	0.245080	1.277723
Leisure and Entertainment	10.293349	29,535.509199
Number of Dining Facilities	0.619990	1.858909
Number of Shopping Facilities	0.032560	1.033096
Area of Educational Zones	0.075189	1.078088
Area of Parks and Green Spaces	0.074557	1.077406
Area of Residential Zones	0.106059	1.111887
Area of Water Surfaces	−0.045183	0.955822
Mining Area	0.027458	1.027838
Road Network Density	0.192943	1.212814
Degree of Spatial Fragmentation	−0.000716	0.999285

The binary logistic regression analysis results (Table 3) show the following regression coefficients for each influencing factor: Leisure and entertainment facilities have a regression coefficient of 10.293 with an odds ratio of 29,535.5, making it the core factor affecting mine–city spatial integration. Dining facilities have a regression coefficient of 0.620 (odds ratio 1.86), confirming a positive impact on spatial integration with increased facility density. Road network density has a regression coefficient of 0.193 (odds ratio 1.21), demonstrating that higher road density enhances population mobility and facilitates spatial integration. Water surface area has a regression coefficient of −0.045 (odds ratio 0.96), reflecting a negative effect where larger water bodies inhibit integration. Regarding commercial density, high-density commercial areas (>0.8 facilities/hectare) have 3.2 times higher integration probability than low-density areas (<0.2 facilities/hectare).

3.2.3. Spatial Integration Evaluation

By performing dimensionality reduction and extracting the main component indicators, a quantitative assessment of the spatial integration degree of the mine–city space in the central urban area of Huaibei City is conducted, along with spatial placement. This is combined with the social context of urban development to provide an in-depth analysis of the spatial pattern characteristics of the central urban area of Huaibei City. In Table 4, the common factors for the 11 indicators mentioned earlier are extracted, with the variance contribution rate representing the proportion of total variance explained by each factor. The higher the value, the greater the extent to which the factor explains the data [50,51].

Table 4. Contribution rates of common factors to variance.

Factor	Variance Contribution	Percentage	Cumulative Percentage
F1	0.121269	52.34%	52.34%
F2	0.043368	18.72%	71.06%
F3	0.043922	18.96%	90.02%
F4	0.023124	9.98%	100.00%

F1 reflects commercial clustering (dining/shopping/leisure); F2 indicates hospitality-driven traffic facilitation; F3 reveals environment–transport tradeoffs; and F4 captures spatial fragmentation impacts from mining legacy.

F1 has a contribution rate of 52.34%, representing the impact of commercial concentration, which dominates the integration of mine–city space.

F2 has a contribution rate of 18.72%, explaining the influence of transportation-related factors.

F3 has a contribution rate of 18.96%, which is mainly associated with the impact of the natural environment on the integration of mine–city space.

F4 has a contribution rate of 9.98%, which is a secondary influencing factor, explaining the impact of spatial fragmentation.

Based on the variance contribution rates, the component matrix is extracted, as shown in Figure 7.



Figure 7. Principal component factor loadings matrix.

Among the factors listed in the table above, the high loadings of the number of dining establishments, leisure and entertainment, and shopping on F1 indicate that the density of commercial activity has a positive impact on mine–city spatial integration. The high loading of the number of hotels on F2 suggests that F2 represents the auxiliary role of commercial facilities. The high negative loadings of water surface area and road network density indicate that natural and transportation conditions constrain mine–city integration. Mining area space and spatial fragmentation have relatively high loadings on the F4 factor; although their impact is smaller, they reflect the secondary limitations imposed by environmental fragmentation on mine–city spatial integration. The rotated component matrix was obtained using the varimax method, and the scores for each factor were calculated accordingly. Using the variance contribution rate of the common factors as weights, a fusion evaluation equation was constructed.

$$\begin{aligned}\text{Mine-City Spatial Integration Score} = 0.5234 \times \text{Commercial Index} + 0.1872 \times \\ \text{Location Index} + 0.1896 \times \text{Transportation Index} + 0.0998 \times \text{Spatial Index}\end{aligned} \quad (3)$$

The specific coefficients for each factor are as follows: commercial index coefficient, 0.5234; location index coefficient, 0.1872; transportation index coefficient, 0.1896; and spatial index coefficient, 0.0998. The commercial index has the highest contribution rate at 52.34%, primarily composed of dining (loading coefficient of 0.988), leisure and entertainment (loading coefficient of 0.845), and shopping (loading coefficient of 0.684).

Based on the various indicator factors and their weights, the following conclusions can be drawn: (1) Commercial factors are the key element in determining the distribution of mine–city spatial integration within the central urban area of Huaibei City; mine–city integration behavior is more likely to appear in business districts and areas with high commercial density. (2) Location and transportation conditions have a certain impact on the distribution of mine–city spatial integration, with spatial integration being more pronounced in areas with convenient transportation. (3) The influence of mine–city spatial integration is extensive, covering the entire central urban area; however, natural water bodies, such as those in collapsed areas, have a negative effect on spatial integration.

Through principal component analysis, the conditions that promote mine–city spatial integration are transformed into specific indicators with corresponding weights. The composite score calculated from these reflects the degree of integration of mine–city space in a given area. These scores can be used to identify and classify mine–city spatial regions with varying levels of integration.

4. Discussion

4.1. Analysis of the Overall Characteristics of High Integration Areas

According to the mine–city spatial integration evaluation map of Huaibei City's central urban area, areas with composite scores between 140 and 225 are defined as high integration areas, as shown in Figure 8. These high-value areas are concentrated in the Xiangshan region, the Lieshan–Yangzhuang mining region, and the Zhangzhuang–Zhuzhuang mining region. These areas are selected as micro-level study subjects to investigate their underlying causes.

As illustrated, the three regions exhibit significant differences across multiple dimensions. By examining the urban functional layout and spatial distribution of mining areas in Huaibei City, the characteristics of each region can be summarized.

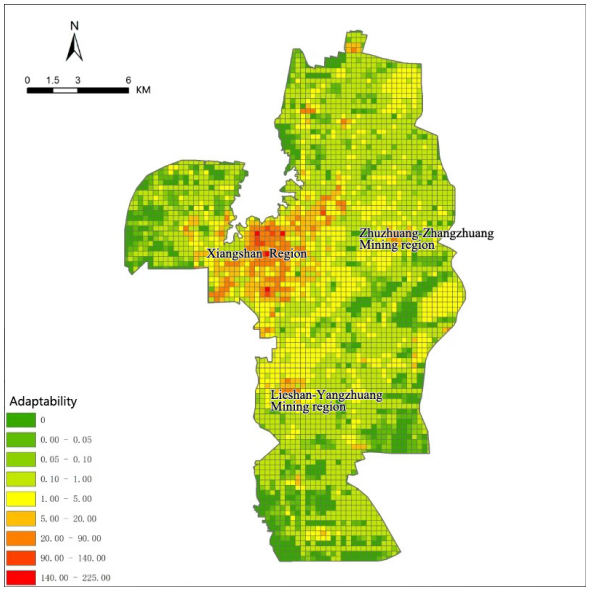


Figure 8. Comprehensive evaluation of spatial integration in Huaibei's Mining City.

4.1.1. Xiangshan Region

The Xiangshan region has evolved into the central urban area of Huaibei City, showcasing the highest degree of integration between mining and urban development, and the most prosperous economy. Coal mining and processing have generated substantial economic revenue for Xiangshan District, bolstering local finances. During the city's early development, key facilities such as the Huaibei Coal Mine General Machinery Plant and the Huaibei Mining Bureau Workers' Hospital were concentrated in Xiangshan, laying the groundwork for urban expansion and energy aggregation. With the advancement of coal mining, Xiangshan District undertook extensive infrastructure projects, including transportation, electricity, and water supply, to enhance urban development. The coal industry created numerous employment opportunities, attracting a significant influx of workers and their families, which led to a population surge from several hundred thousand in the early 1980s to approximately two million today. This population growth spurred urban expansion, with Xiangshan's urban area continually enlarging and its functions becoming more comprehensive, encompassing education, healthcare, and public services. The integration of mining and urban development has positively influenced the city's growth, positioning Xiangshan District as the true city center of Huaibei.

4.1.2. Lieshan–Yangzhuang Mining Region

Lieshan Coal Mine, the first established mine in the Huaibei mining area, is surrounded by natural landscapes such as Woniu Mountain, Phoenix Mountain, Wohu Mountain, and Qinglong Mountain, endowing the Lieshan–Yangzhuang region with rich historical depth. Adjacent to Yangzhuang Coal Mine are attractions like the national wetland Nanhu Park and the National Mining Museum, making it a vital coal production base that significantly contributes to the local economy. The mining activities have not only provided ample employment but also stimulated economic development in surrounding areas, promoting the prosperity of related industries such as transportation, logistics, and services. The development trajectory of the Lieshan–Yangzhuang mining area reflects the evolution of Huaibei's coal industry and its spatial integration with the city, forming the southwestern center of Huaibei's central urban area and serving as a strategic anchor for the city's future southward expansion.

4.1.3. Zhuzhuang–Zhangzhuang Mining Region

As integral parts of the Huaibei Mining Group, Zhangzhuang and Zhuzhuang Coal Mines have led to the establishment of administrative units like Minshanji Street due to the integration of mining and urban spaces. Coal mining and processing have directly generated substantial economic income and propelled urban expansion, with Minshanji Street's urban area continuously growing and its functions becoming more complete. To meet the living needs of a large population, numerous residential communities, schools, hospitals, and other facilities have been constructed around the Zhuzhuang–Zhangzhuang mining area, enhancing residents' quality of life. Additionally, the perspective on coal mining subsidence areas has shifted, transforming abandoned subsidence zones into ecological parks and farmland within Huaibei, thereby improving the urban environment. The development of Zhangzhuang and Zhuzhuang Coal Mines has not only brought significant economic benefits to Minshanji Street but also promoted population aggregation and urbanization. Through industrial upgrading and diversified development, the integration of the city and mining areas has simultaneously optimized the economic structure. Government policy support and environmental management measures have further enhanced the city's overall competitiveness. Collectively, these factors have made the Zhuzhuang–Zhangzhuang mining area a favorable eastern support in Huaibei's territorial spatial planning.

4.2. Analysis of Spatial Transformation Differences in Highly Integrated Areas

Based on the characteristics and influencing factors of mining–urban spatial integration, observations of public service facility configurations and commercial formats in the Lieshan region, Lieshan–Yangzhuang mining region, and Zhuzhuang–Zhangzhuang mining region reveal the following distinct features:

- Xiangshan Region retains extensive residential areas and mining bureau facilities, exhibiting strong centrality. Commercially, it boasts diverse formats and a prosperous economy, with high residential density and spatial vitality. As the core of the city's commercial district, it faces urgent needs to redevelop inefficient industrial and mining land. The area hosts numerous shopping centers, brand stores, and restaurants, forming a comprehensive and diversified commercial hub that attracts a large consumer base. There is an increasing demand for ecological restoration, with many internal subsidence areas requiring transformation into parks and green spaces.
- Zhuzhuang–Zhangzhuang Mining Region exhibits a modern urban atmosphere, reflecting the industrial style post-mining transformation. While some mining production buildings and facilities remain, the area predominantly consists of large-scale worker villages. Commercial activities are relatively low-end and limited in number, primarily serving residents' basic daily needs through small restaurants and convenience stores. Future urban renewal efforts must focus on renovating old residential areas and introducing younger demographics and modern commercial formats to revitalize spatial vitality and promote mining–urban integration.
- Lieshan–Yangzhuang Mining Region, as the core of the city's southern commercial district, blends traditional and modern mining elements. The area preserves historical context and offers diverse facilities, including large-scale water parks and spontaneously formed pedestrian streets, contributing to strong regional vitality. Commercial formats are relatively stable, mainly comprising traditional shops and supermarkets that meet residents' basic needs. This stability enhances the level of mining-urban integration in the area.

Comparing the public service facilities and commercial formats of the Xiangshan, Lieshan–Yangzhuang, and Zhuzhuang–Zhangzhuang regions reveals different models of mining–urban spatial integration. Xiangshan focuses on a modern commercial center

with diverse and numerous formats; Lieshan–Yangzhuang retains traditional mining city cultural features with stable commercial formats; Zhuzhuang–Zhangzhuang emphasizes life service-oriented formats with relatively fewer commercial establishments. These differences reflect the varied strategies and development paths adopted during the mining–urban integration process in each region.

5. Conclusions

This study analyzes the historical evolution and current status of mine–city spatial integration in the central urban area of Huaibei City, exploring the characteristics of this integration and its influencing factors. The findings are outlined below.

5.1. Characteristics of Mine–City Spatial Evolution

Huaibei's mine–city spatial structure has undergone several stages, from its nascent phase in the 1960s to a transformative period post-2000, where mining areas became integral components of urban space. However, the integration process exhibited certain characteristics: lagging development, clustered formations, transportation-led expansion, and spatial continuity. These traits offer new perspectives for future urban spatial development.

5.2. Influencing Factors of Mine–City Spatial Integration

The density of commercial activities, particularly leisure, dining, and shopping facilities, is a core factor promoting mine–city spatial integration. In terms of location, the expansion of educational and residential areas provides a population base for integration, but also presents limitations. Transportation factors, such as a dense road network and good connectivity, positively influence integration. Conversely, natural environmental factors like water bodies (e.g., coal mining subsidence areas) negatively impact integration by hindering urban mobility.

5.3. Analysis of High Integration Areas

- Xiangshan Area: As Huaibei's city center, it exhibits the highest level of mine–city integration and economic prosperity. The area boasts abundant commercial facilities, comprehensive public services, and a high residential density, making it the urban core.
- Lieshan–Yangzhuang Mine Area: This region blends traditional and modern mining elements, preserving rich historical context and natural landscapes. Its commercial activities are primarily shopping-oriented, forming a relatively stable commercial pattern.
- Zhuzhuang–Zhangzhuang Mine Area: Reflecting a more modern mining landscape, this area focuses on life services with fewer commercial establishments. It faces significant challenges in urban renewal and enhancing spatial vitality.

5.4. Variability in Spatial Transformation

- Xiangshan Area: Future development aims to enhance its value as the city center, necessitating the redevelopment of inefficient industrial and mining lands and strengthening ecological restoration efforts.
- Lieshan–Yangzhuang Mine Area: As the southern commercial hub, it needs to boost regional vitality and diversify commercial activities while preserving historical context.
- Zhuzhuang–Zhangzhuang Mine Area: The pilot area implements the "industrial heritage + community revitalization" renewal model by rehabilitating old residential communities and introducing youth-oriented businesses, thereby enhancing spatial vitality and promoting mining city integration.

The mine–city spatial integration evaluation framework proposed in this study has demonstrated significant effectiveness through its empirical application in Huaibei City.

Core influencing factors identified—such as the dominant role of commercial facility density—have been partially validated in comparative analyses of other coal-resource-based cities like Huainan and Fushun. However, the framework's applicability is significantly constrained by city scale, the coal mining subsidence areas ratio, and historical context. For instance, in cities with minimal water bodies (e.g., Hegang), the weighting of the "water-induced inhibitory effect" should be reduced; in growing resource-based cities, prioritizing transportation network integration over commercial facilities is recommended.

In summary, the integration of mining and urban spaces in coal resource-based cities is a complex process shaped by multifaceted factors. Future research should track dynamic integration patterns and explore more effective models for integrated spatial development; establish cross-regional case databases to develop dynamic adjustment mechanisms for the evaluation framework, enhancing its universality; and investigate pathways at regional, city, and district scales through multi-scenario simulations predicting urban spatial trajectories, thereby providing actionable strategies for sustainable spatial planning.

While current limitations in data acquisition and methodology preclude exhaustive insights, this study lays the groundwork for potential solutions to advance this field.

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